The NOvA Experiment

Martin Frank
University of Virginia
on behalf of the NOvA Collaboration

CIPANP 2012
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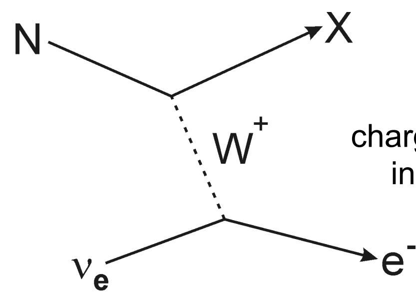
PHYSICS

- NOνA:
  - NuMI: Neutrinos at the Main Injector (ν_μ)
  - Off-Axis: monoenergetic beam (2 GeV)
  - ν_e Appearance

$$P(\nu_\mu \rightarrow \nu_e) = f(\theta_{13}, \theta_{23}, \delta_{\mathrm{CP}}, \text{mass hierarchy}, ...)$$

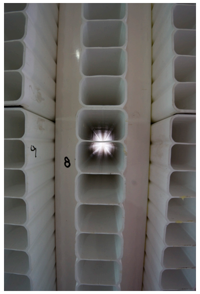
- Physics Goals:
  - resolve θ_{23} octant
  - measure CP-violating phase angle δ_{CP}
  - resolve the neutrino mass hierarchy (normal vs. inverted)

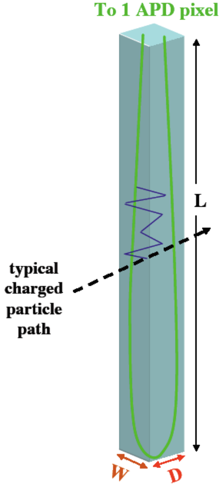
Neutrino Detection



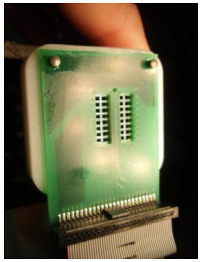
charged-current interaction

- We want to detect electron neutrinos (ν_e):
  - This requires a large detector mass and good electromagnetic (EM) shower resolution.
- Solution: "Fully" Active Detector
  - use low Z materials: PVC extrusions filled with liquid scintillator
    - provides radiation length ~ 40 cm
    - provides Molière radius ~ 11 cm
  - each extrusion contains one wavelength-shifting fiber
  - ends of fiber read out by avalanche photo-diode (APD)
  - detector optimized to differentiate EM showers from hadronic showers

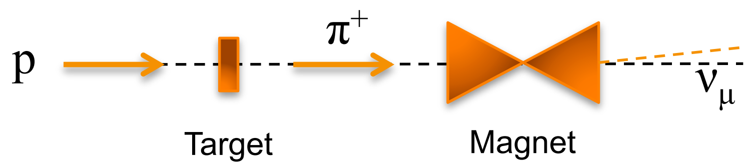


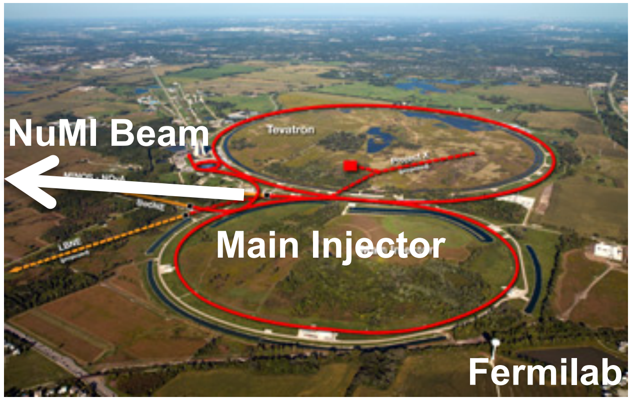


Avalanche Photo-Diode
APD

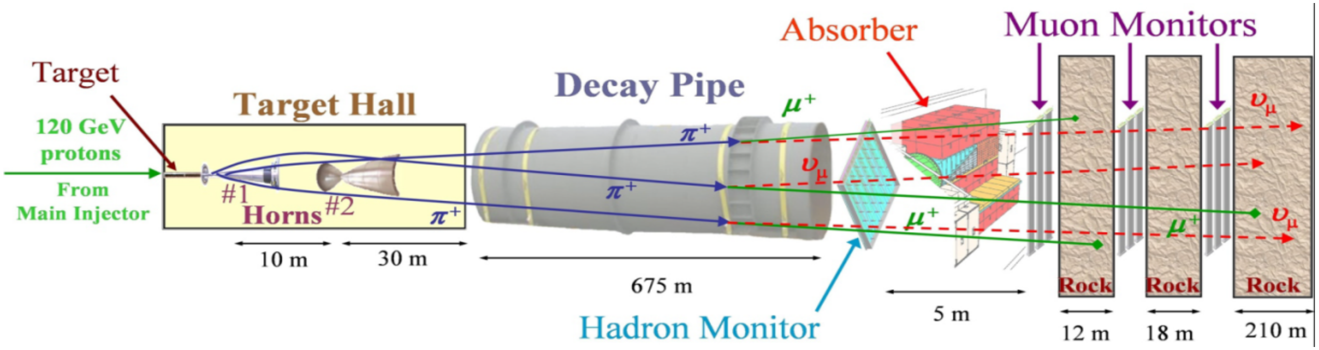


- Detector Structure:
  - 32 PVC tubes → 1 module
  - 12 modules → 1 (*x*- or *y*-) plane
  - 32 planes → 1 block

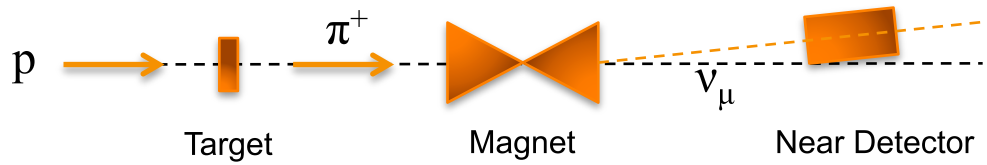


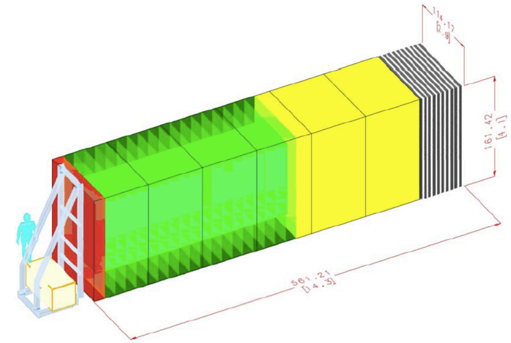


NuMI Beamline

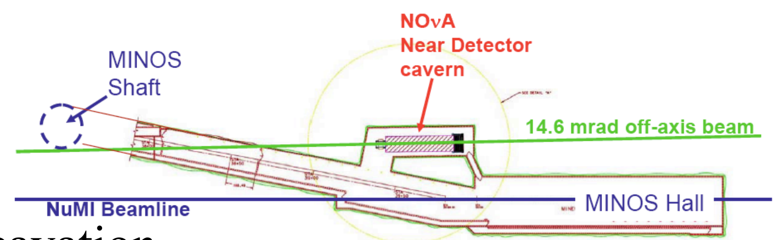


- NuMI: Neutrinos at the Main Injector
- Beam delivered to several neutrino experiments since 2005:
  - MINOS, MINERνA, and ArgoNeut
- Beam shutdown: May 2012 – April 2013
  - upgrade beam:
    - increase beam power from 300 kW to 700 kW
    - reduce cycle time from 2.2 s to 1.3 s
    - upgrade graphite target and magnetic focusing horns
  - near detector cavern excavation

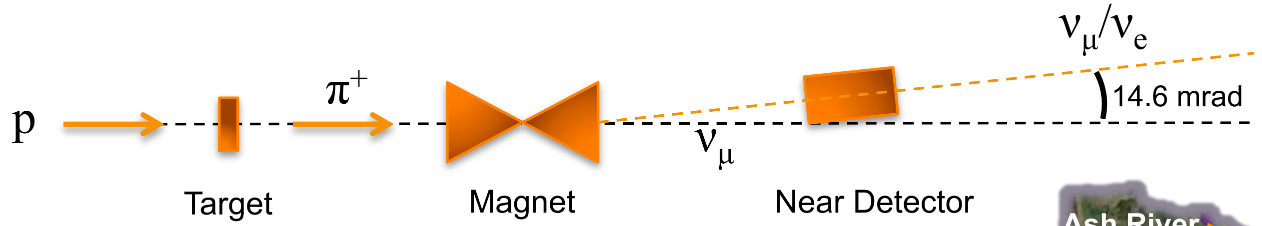


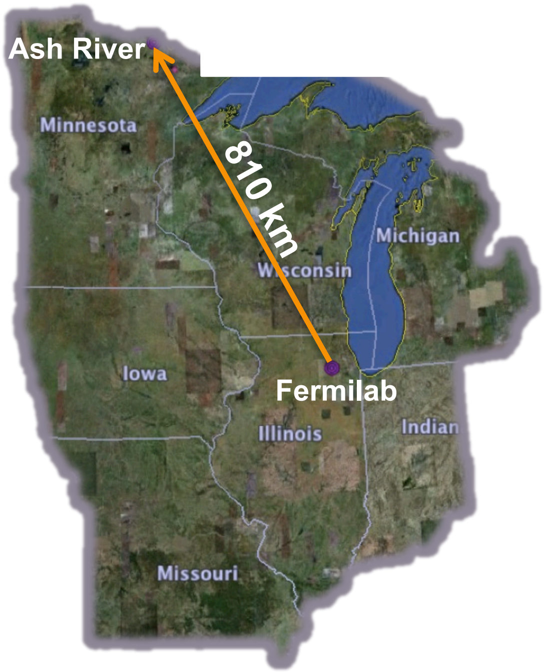


NEAR DETECTOR(S) AT FERMILAB



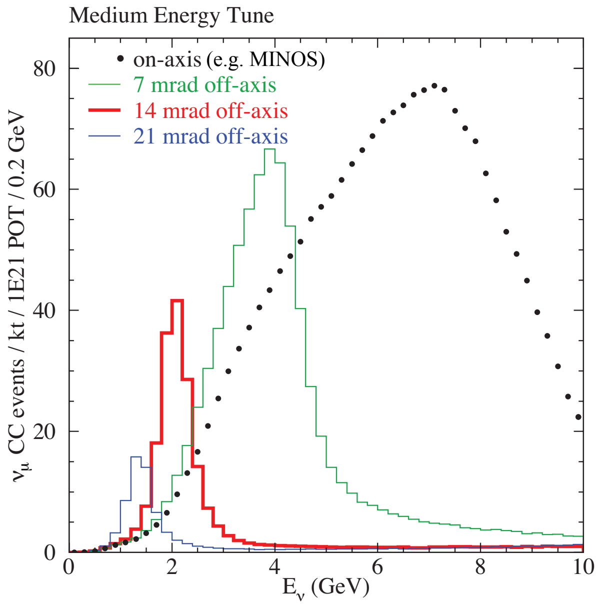
- 105 m underground:
  - beam is aimed downward
  - using MINOS near detector shaft
  - construction will start after cavern excavation
  - 4 m × 4 m × 14 m
  - 266 tons = 639 modules = 20,448 channels
- on the surface:
  - prototype detector to test detector technology
  - completed May 9th, 2011
  - 3 m × 4 m × 14 m
  - 222 tons = 496 modules = 15,904 channels
  - successful running until beam shutdown last month



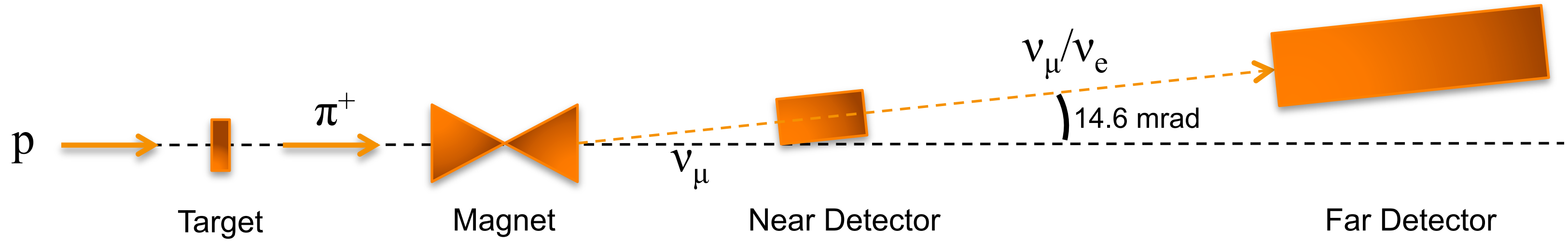


The Beam

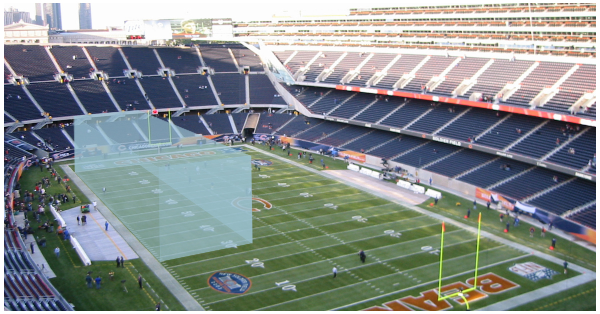
- Baseline (L = 810 km):
  - The neutrino beam travels from Fermilab (Batavia, IL) to Ash River, MN through the earth's crust.



- Energy (E_ν = 2 GeV):
  - The NuMI medium energy tune is shown on the left.
  - We can achieve a narrowly distributed neutrino energy by placing the far detector 14.6 mrad off the beam axis.

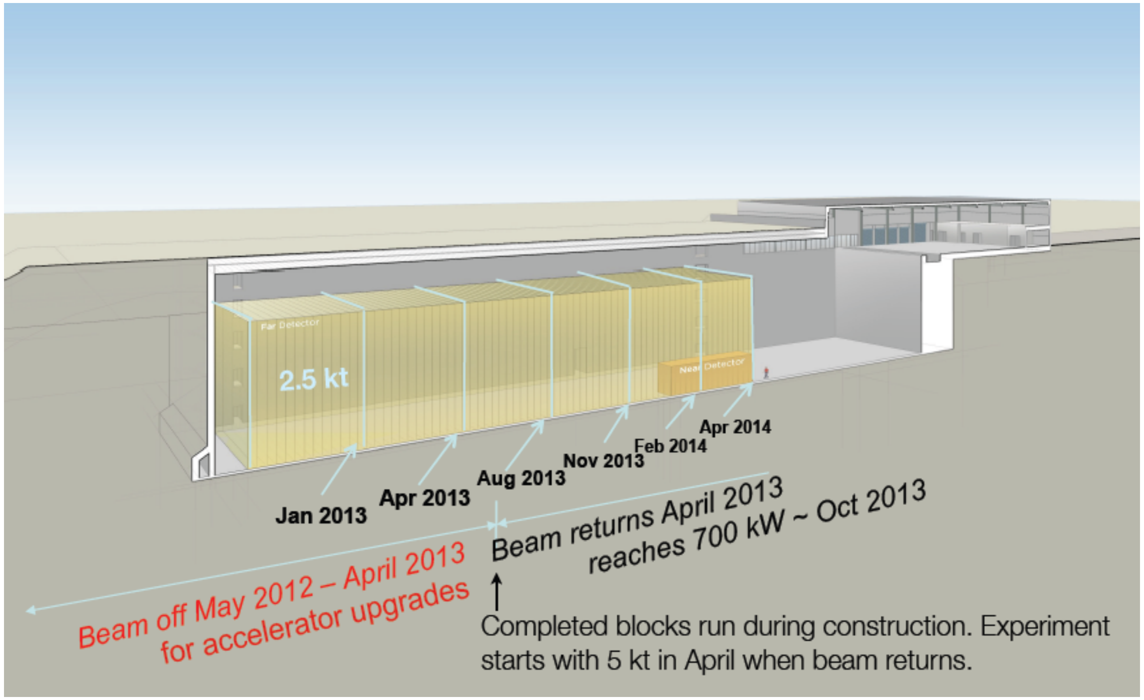


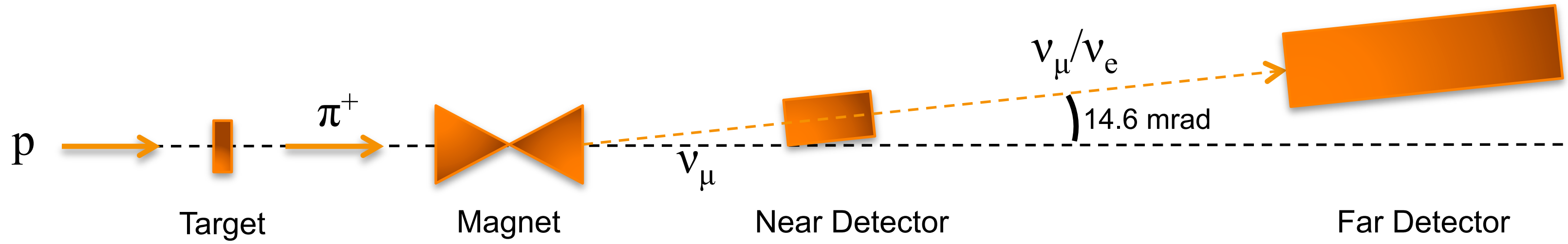
FAR DETECTOR



compared to Soldier Field

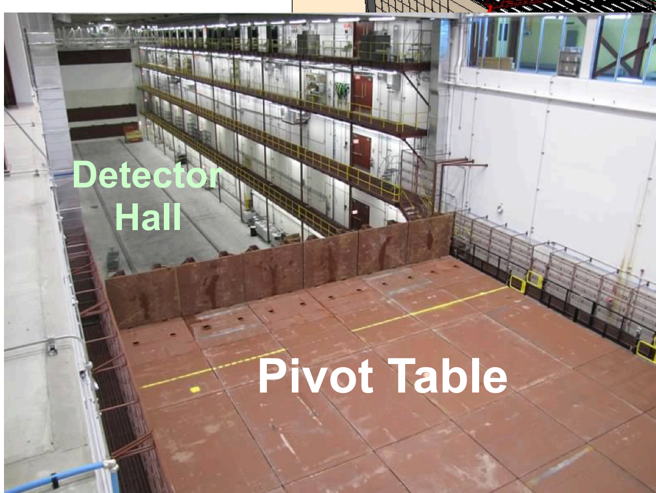
- **14+ kt** detector:
  - 16 m × 16 m × 64 m
  - = 29 blocks
  - = 11,136 modules
  - = 356,352 channels
- building dedicated a month ago (April 2012)
- detector construction imminent

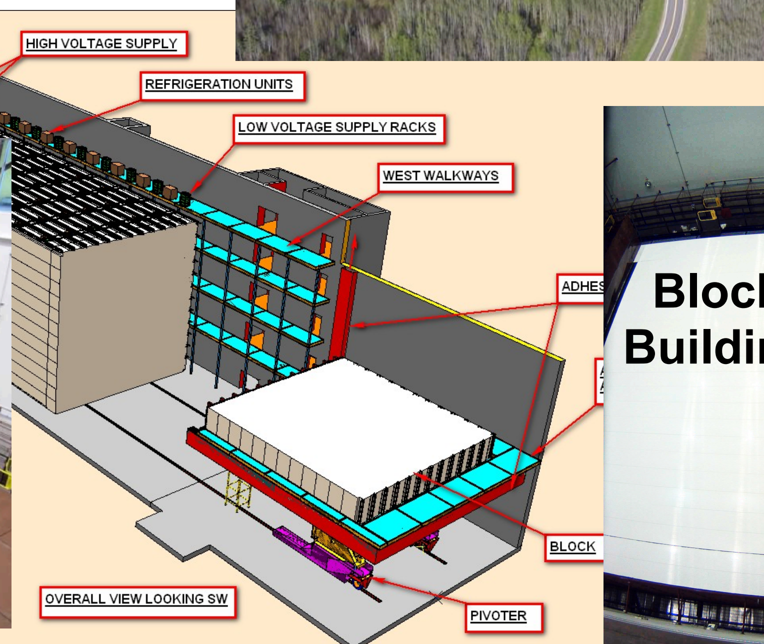


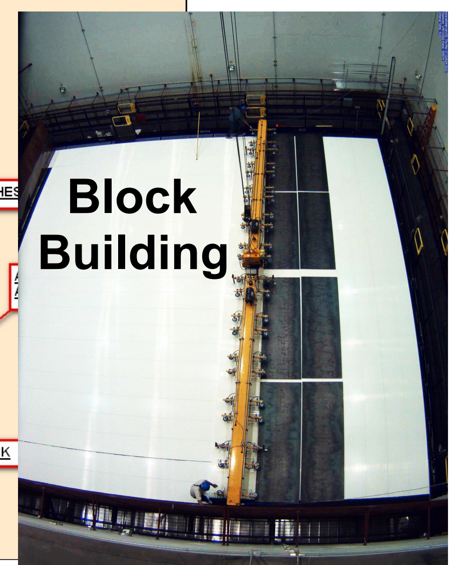


Far Detector

<u>14,000+ tons</u>







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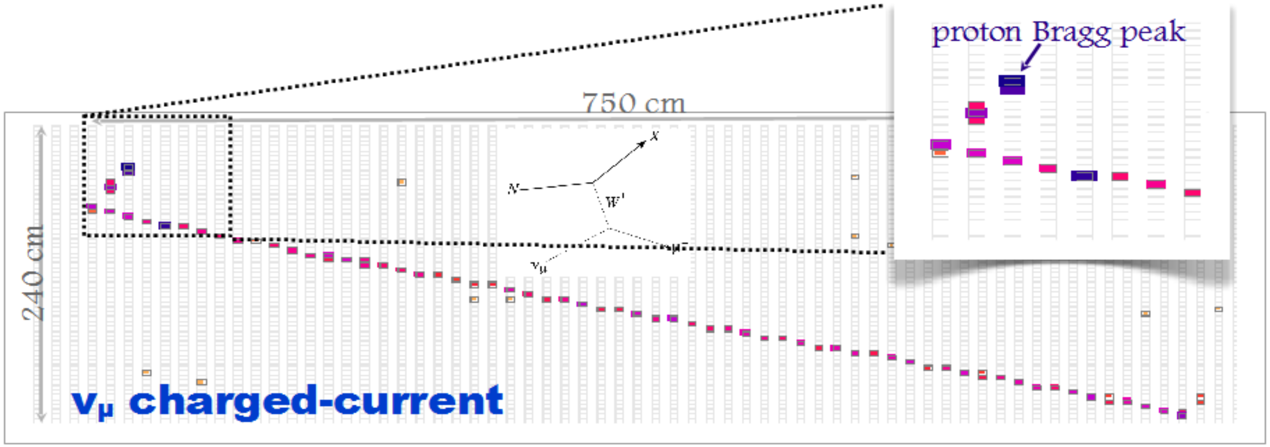
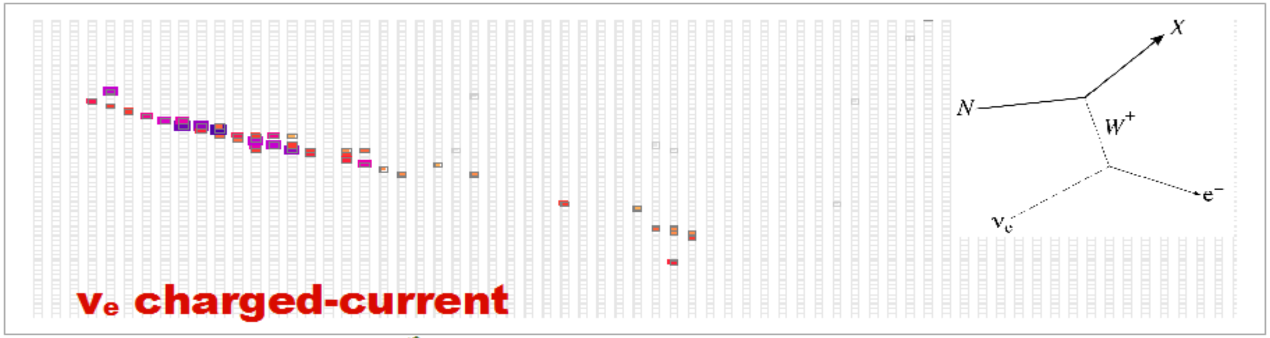
Simulated Event Signatures



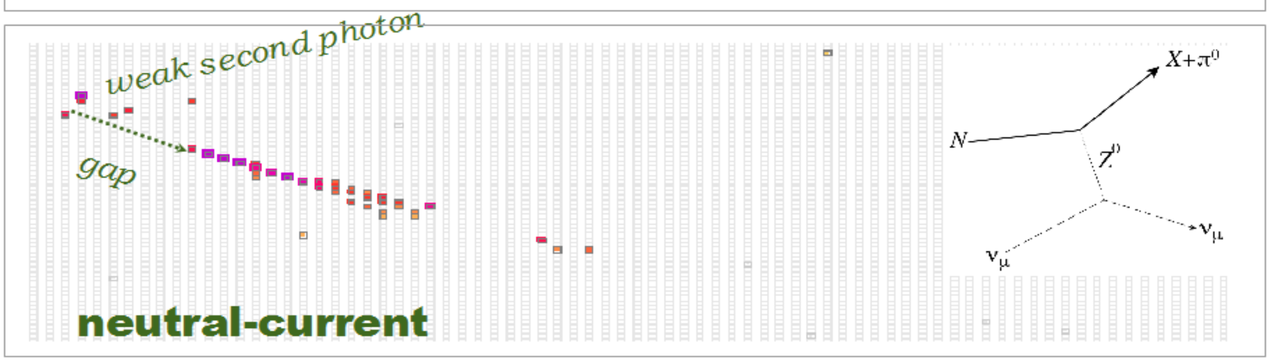
ν_μ charged-current

- ✓ long, well-defined muon track
- ✓ short proton track with large energy deposition at end



ν_e charged-current

- ✓ single EM shower
- ✓ characteristic EM shower development

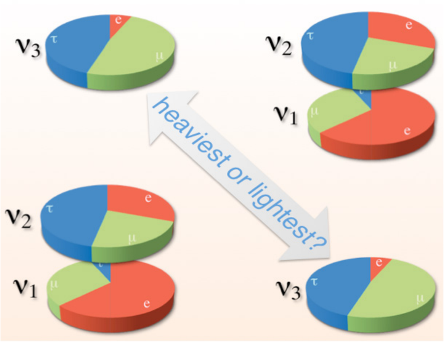


neutral-current with π^0 final state

- ✓ multiple displaced EM showers
- ✓ possible gaps near event vertex

Extracting Nature's Parameters

$$P(\nu_\mu \rightarrow \nu_e) \quad P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) \approx \underline{\sin^2(2\theta_{13})}\,\underline{\sin^2(\theta_{23})}\,f^{\pm}(\underline{L,E},\Delta m^2_{31})$$



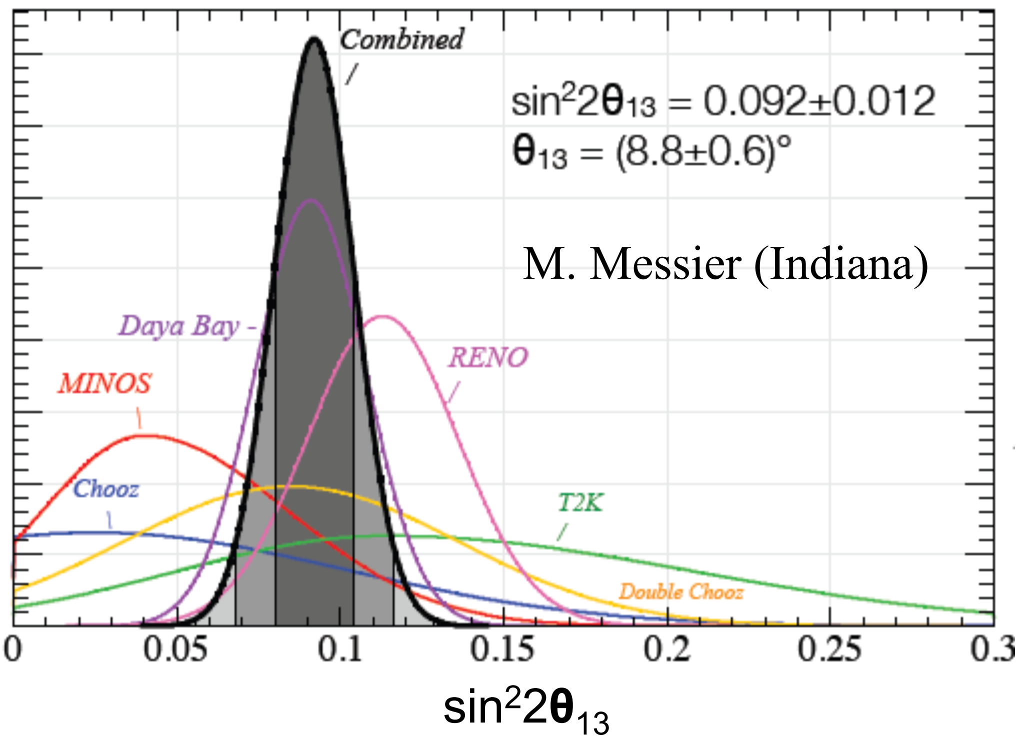
$$+ \left\{\underline{\cos\delta_{CP}}\cos\frac{\Delta m^2_{31}L}{4E} \mp \underline{\sin\delta_{CP}}\sin\frac{\Delta m^2_{31}L}{4E}\right\}$$

$$\times\; 2\frac{\Delta m^2_{21}}{\Delta m^2_{31}}\sin(\theta_{13})g^{\pm}(L,E,\Delta m^2_{31},\theta_{12},\theta_{23})$$

- The NOvA baseline (L = 810 km) and neutrino beam energy (E = 2 GeV) place our detector at the first $\nu_\mu \rightarrow \nu_e$ oscillation peak.
- This allows us to extract the following terms by measuring the ν_e appearance rate:
  - $\sin^2 2\theta_{13}$: the leading term in this equation has already been measured and it is large!
  - $\sin^2\theta_{23}$: we can gleam information about the θ_{23} octant from the leading term.
  - δ_{CP}: using the measured value of θ_{13}, we can determine the CP-violating phase angle.
  - mass hierarchy: depending on the sign of $\Delta m^2_{31} \sim \Delta m^2_{32}$, the oscillation probability is either enhanced or suppressed. This difference can be determined by comparing neutrino running with anti-neutrino running.

In Light of Recent Results …

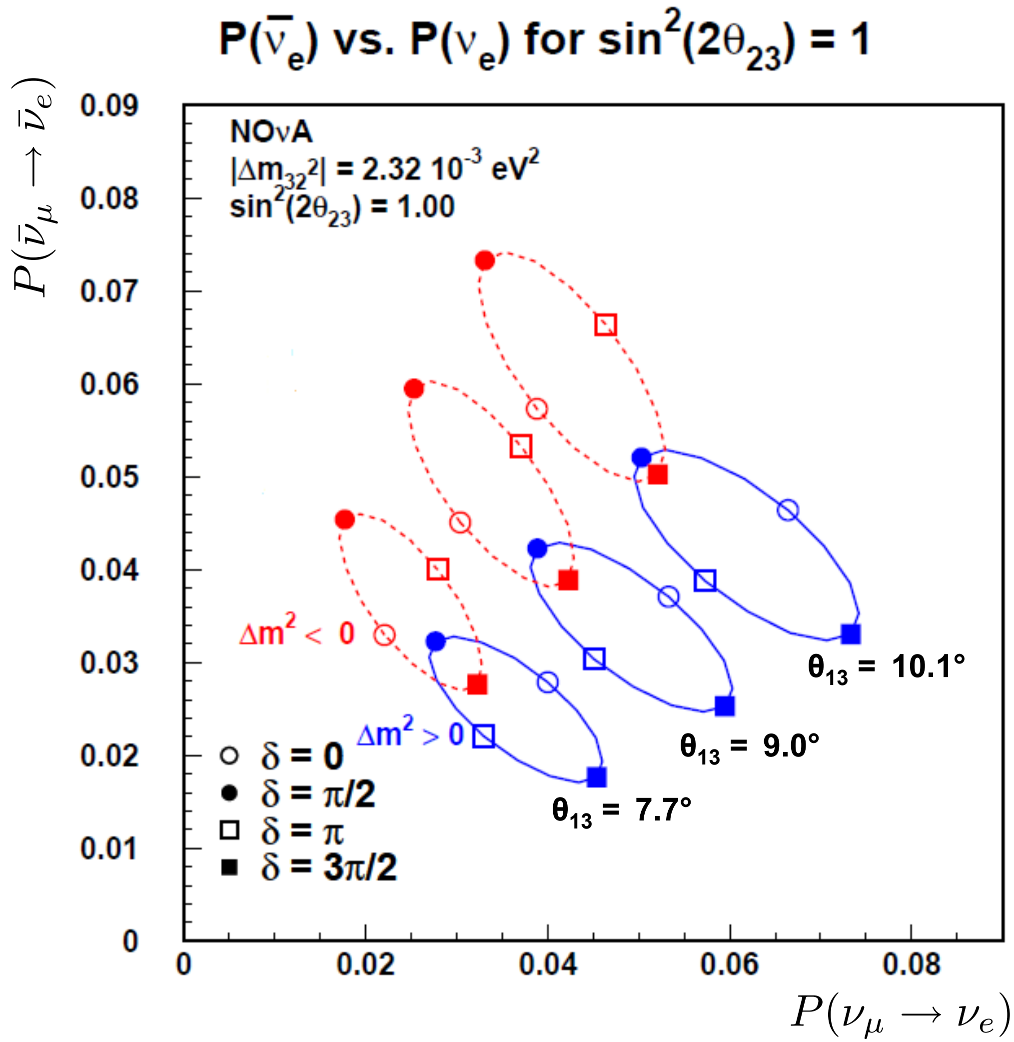
- θ_{13} has been measured and it is large!
- This is excellent news for us!
- Below is a combination of the most recent measurements.



- Daya Bay 0.092 ± 0.017
  - ✓ arXiv:1203.1669v2 [hep-ex]
- RENO 0.113 ± 0.023 (revised)
  - ✓ arXiv:1204.0626v2 [hep-ex]
- Reactor Average
  - ✓ 0.099 ± 0.014
- Combined Average
  - ✓ 0.092 ± 0.012

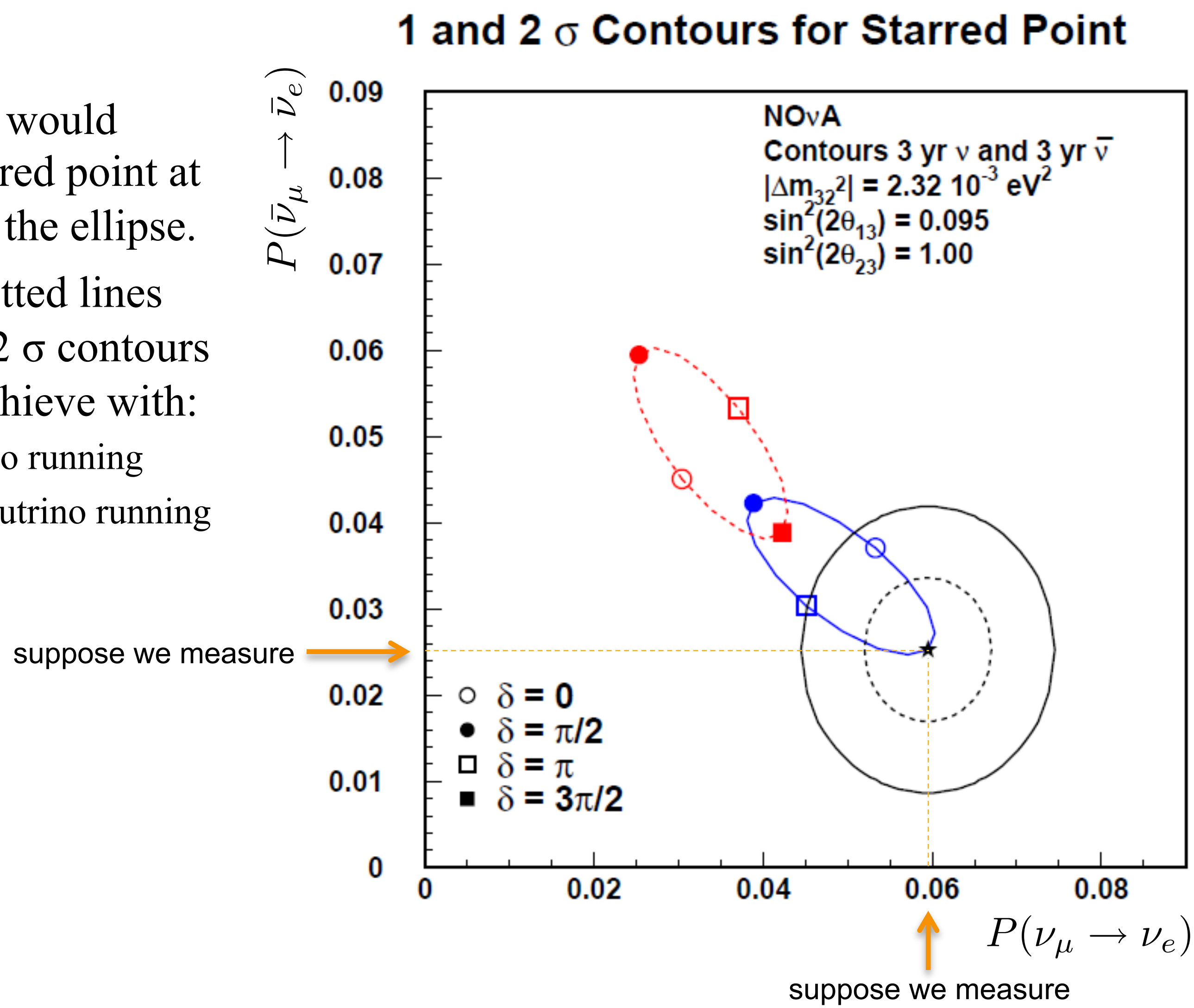
NOνA Physics Reach

- We will measure the appearance probability of electron neutrinos and anti-neutrinos (the two axes).
- The plotted points give the calculated values for different values of δ_{CP} and for the normal and inverted mass hierarchies.
- The large value of θ_{13} (8.8°) gives us better separation between the normal and inverted mass hierarchy.

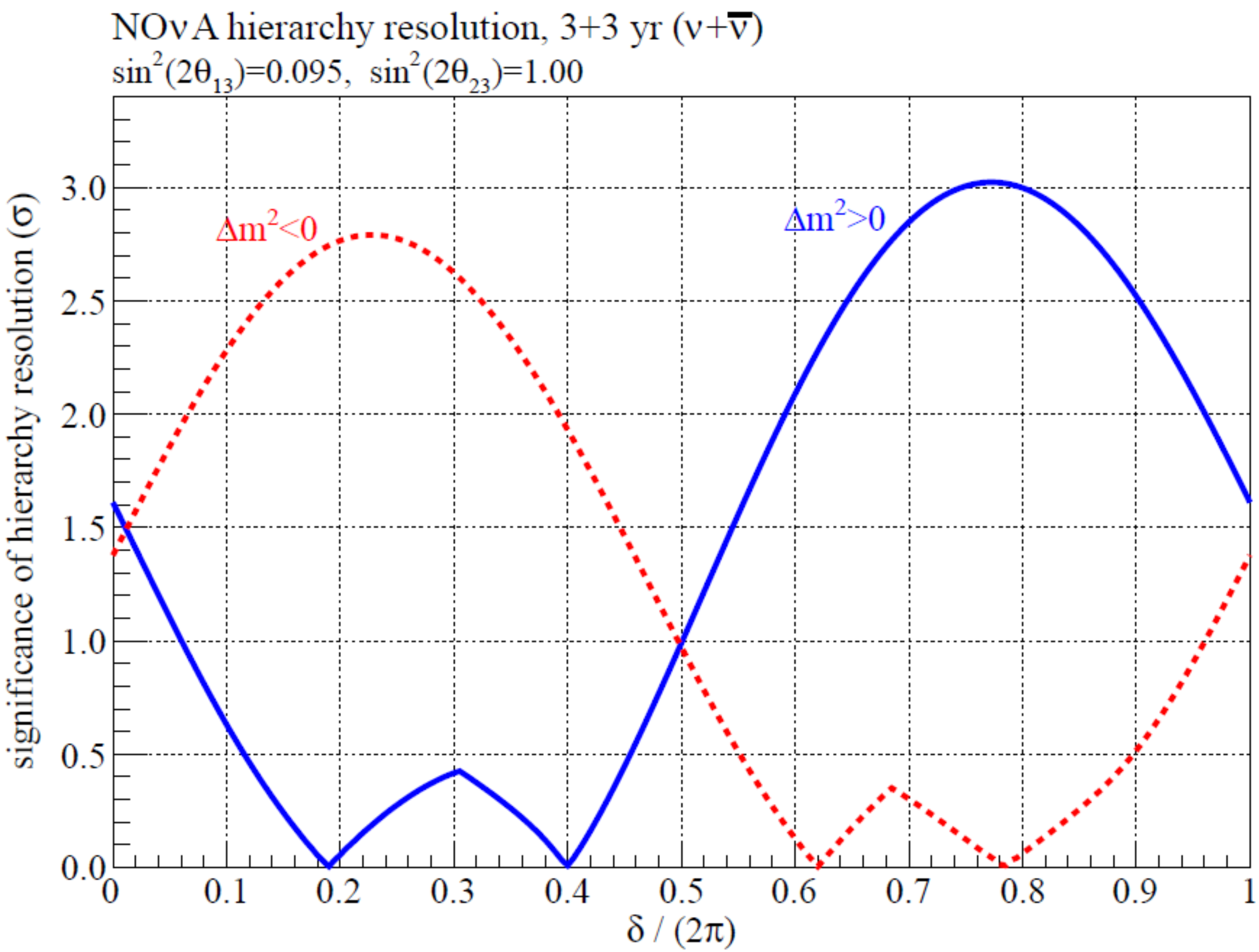


NOνA Physics Reach

- Assume that we would measure the starred point at the extremity of the ellipse.
- The bold and dotted lines show the 1 and 2 σ contours that we could achieve with:
  - 3 years neutrino running
  - 3 years anti-neutrino running

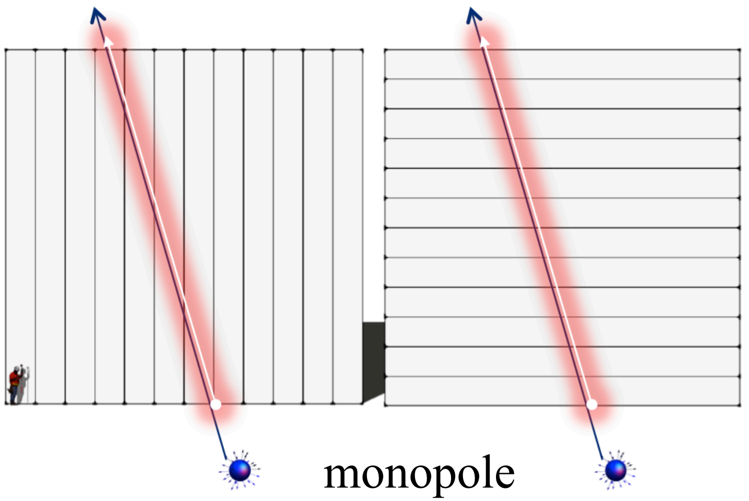


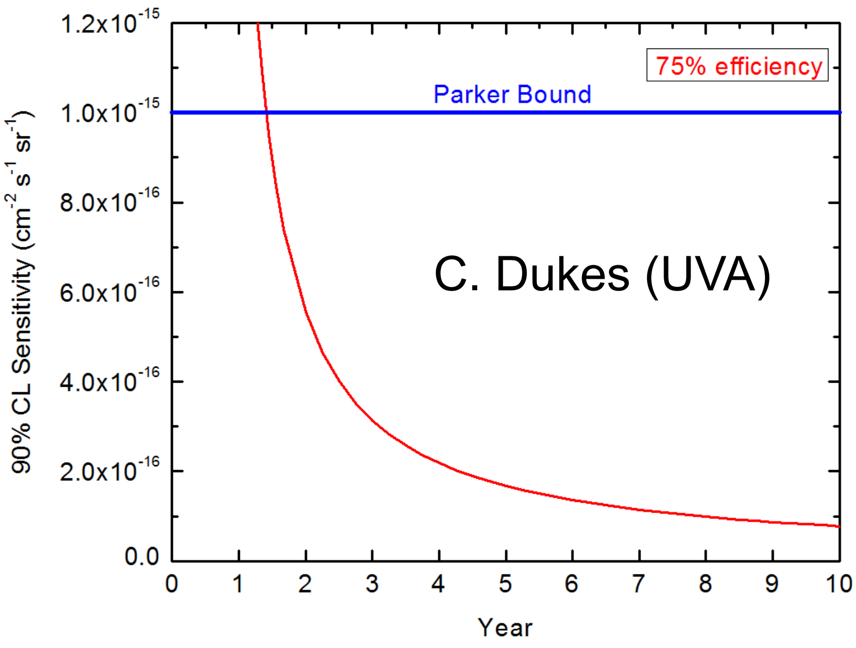
Can We Resolve The Mass Hierarchy?



Exotic Searches

- We have a massive detector, so we do not have to look exclusively at the NuMI beam.
- Monopoles:
  - highly ionizing, slow moving particles
  - the plot on the right shows the flux sensitivity for straight lines going through a NOνA-like detector
- Supernova
  - entire detector gets flushed with cosmic neutrino events
- WIMP (Weakly Interacting Massive Particle)
  - highly energetic neutrinos coming from the sun





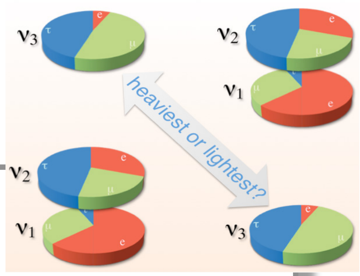
SUMMARY

- Far Detector construction will begin within the next few months and we expect to turn our first blocks on this fall.
- We are excited to start investigating neutrinos from the NuMI beam and pin down δ_{CP}, the mass hierarchy and the θ_{23} octant.
- We will use our detector as an eye to the universe and are excited about what we might learn.
- We do not only have a massive detector, but also a massive collaboration of dedicated people!

150+ scientists and engineers from 25 institutions from 5 countries

Back-Up Slides

Extracting Nature's Parameters



$P(\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_e)$

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EXTRACTING NATURE'S PARAMETERS

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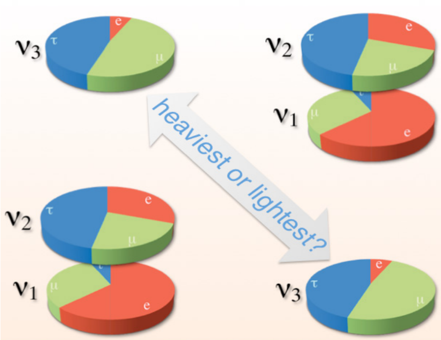

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